

## A Numerical and Experimental Study of Wind Turbine Unsteady Aerodynamics

Earl Duque, Robert Kufeld

Accurate, reliable, and robust numerical predictions of the power required to turn the main rotor blades of a rotorcraft remain a challenge to the industry. Although various numerical methods do exist and have been used in the design of many different aircraft, there still remain some questions regarding the prediction of the maximum power required. Many of the existing theories do not work well in this flight regime. One possible flaw is our lack of understanding of how a rotor blade stalls along the inboard radial locations.

To address this lack of understanding, NASA has formed a collaborative effort with the Department of Energy's (DoE) National Renewable Energy Laboratory (NREL) to investigate the unsteady aerodynamics of a horizontal axis wind turbine (HAWT). The main purpose of this project is to gain a better understanding of a wind turbine's unsteady aerodynamics. By improving our understanding of this machine's aerodynamic environment, we simultaneously improve our capability to properly model rotorcraft rotor blades.

In this effort, researchers use advanced rotorcraft computational fluid dynamics (CFD) methods to simulate the wind turbine. Solutions based on the Reynolds-averaged Navier-Stokes equations have been obtained as illustrated in figure 1. Concurrently,

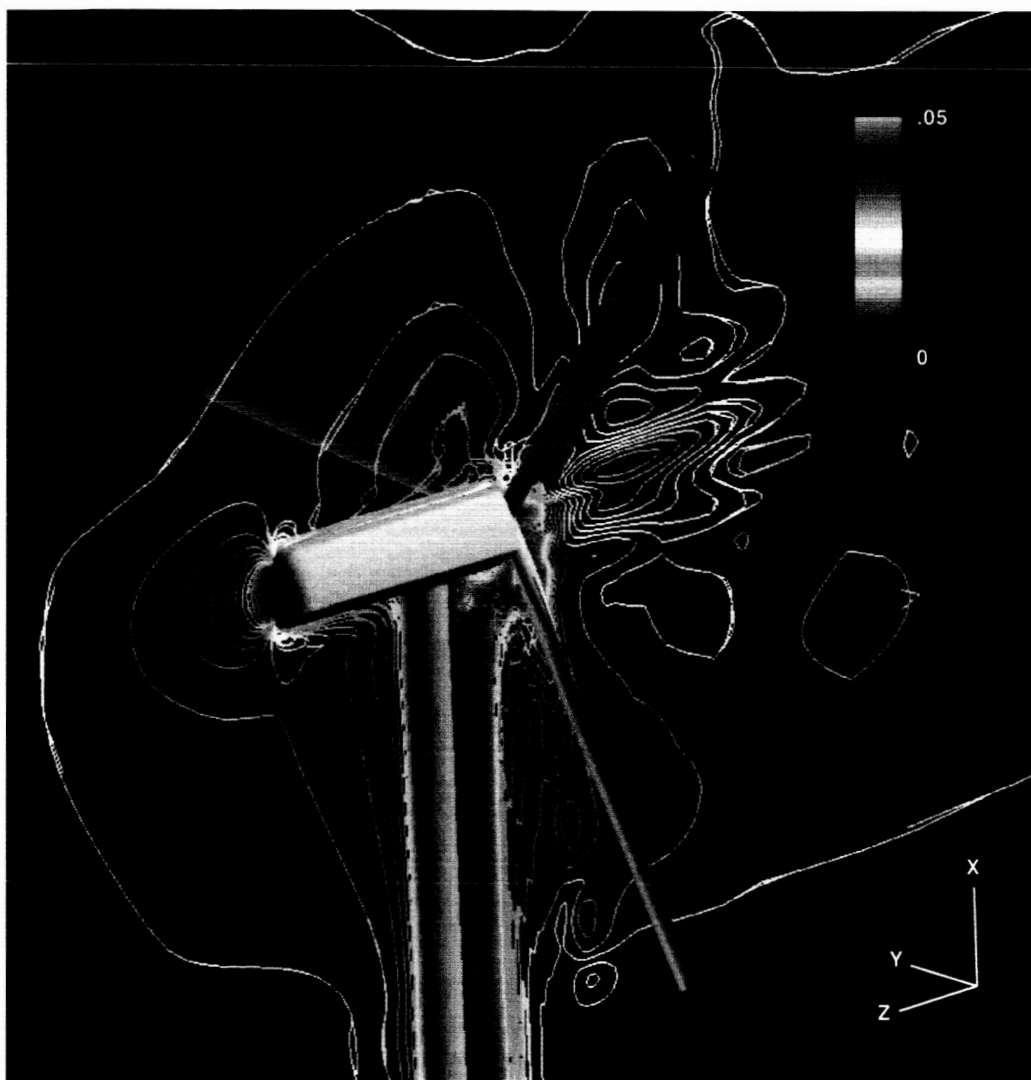


Fig. 1. Computed velocity contours on the NREL Phase 2 Unsteady Aerodynamics Experiment.

NREL has installed and will test their Unsteady Aerodynamics Experiment in NASA's 80- by 120-Foot Wind Tunnel. This test is the largest and most comprehensive wind tunnel test of an HAWT in the world. It will provide extensive unsteady data regarding, for example, pressure, air loads, and dynamic blade response. The information gathered from the experimental data, combined with the knowledge obtained through the computations, forms the nucleus for the development of more accurate semi-empirical rotor design methods. In addition, the knowledge gained through this collaborative program will have a major effect on the understanding of other rotary flow fields such as those of tilt rotors and helicopters.

This collaborative effort directly addresses aerodynamic issues relevant to both rotorcraft and wind turbines. By utilizing scientific resources from both NREL and NASA, we have been able to advance

our understanding of the aerodynamic behavior of rotor blades to the benefit of both industries.

**Point of Contact: E. Duque**  
**(650) 604-4489**  
**eduque@mail.arc.nasa.gov**

## Analysis of On-Blade Control

**Mark V. Fulton**

Because high levels of helicopter vibration are bothersome to pilots, passengers, and on-board equipment, efforts are under way to develop improved active rotor concepts for vibration control. In an effort to explore the benefits of on-blade controls, a small-scale active rotor was previously tested in the Army/NASA 7- by 10-Foot Wind Tunnel. The rotor shown in the figure contained one elevon (or control surface) per blade which was actuated by piezoceramic bimorph actuators to reduce vibratory blade loads. Previous reports have described the test in detail along with preliminary 2GCHAS (Second Generation Comprehensive Helicopter Analysis System) calculations used for data correlation and for explaining the observed aeroelastic phenomenon. More recently, CAMRAD II (Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics) calculations were made to study several model features, including tip loss and elevon dynamics, and to allow further forward flight vibratory loads comparisons. In all cases, the control consisted of elevon deflection, and the response consisted of blade root bending and torsion moments.

In hover, the predictions captured the basic aeroelastic effects evident in the data, including elevon reversal and aeroelastic resonant peaks. For some cases, however, the magnitude of the predictions significantly differed from the experimental measurements. For example, the calculated peak torsion moment response (to elevon deflection) was only 60% of the experimental peak response for a nominal hover condition. A parameter found to be rather effective in changing the torsion resonant peak was tip loss—ignoring the aerodynamic loads for the outboard 2% of the blade increased the torsion peak



*Fig. 2. NREL Phase 6 Unsteady Aerodynamics Experiment installed in 80- by 120-foot wind tunnel test section.*